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# Monitoring Corrosion Process of Reinforced Concrete Structure using FBG Strain Sensor.

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*Abstract*—**Major factor effects the durability of a concrete structures is cracks formation induced by expansion of reinforcement corrosion. Therefore, monitoring and evaluating the corrosion level of structure is essential for its safety. In order to monitor corrosion, an innovative methodology based on Fiber Bragg Grating sensing technique was developed and tested in this paper. The method uses the volume of corrosion products to detect the evolution of corrosion. The corrosion process was accelerated by impressed current technique. A correlation between the FBG wavelength shift and corrosion percentage of reinforcement was found.**

***Index Terms*—*Steel reinforcement concrete, corrosion monitoring, fiber Bragg grating (FBG), wavelength shift.***

## I. Introduction

STEEL reinforced concrete (RC) is considered as one of the most popular composite methods embraced by modern construction all over the world, owing largely to a number of reasons such as vast availability of raw materials, flexibility in construction and excellent cost-performance [1]. While embedded steel reinforcements help to improve tensile resistance of structural member, concrete provides cover to protect the steel reinforcements from corrosion. Nevertheless, corrosion of steel reinforcements can usually be found in RC members that have been put under service for long-time, especially in chloride-borne environments [2]. In addition, corrosion problem can be profound for RC members which have cracked to an extent that moisture and other corrosion-initiating chemicals can easily penetrate into. This initiates durability issues, which if not attended properly could pose serious threats to the integrity of a whole structure.

The effect of steel reinforcement corrosion on a structure is twofold: firstly, it lowers stiffness and result in loss of structural integrity because of the reduced useful steel cross section area; secondly, the formation of expansive corrosion products introduces undesirable stresses that initiate concrete cracking, resulting in further loss of structural stiffness. A corrosion level of 9 % by weight loss of reinforcement can lead to a reduction of the steel-concrete bond strength by two-third of the un-corroded bond [3], in other words 9% corroded bar had one third bond strength of non-corroded bar. However, the bond strength could possibly be slightly enhanced at low corrosion level due to the expansive pressure and the increment of frictional strength between the reinforcement and surrounding concrete [3]. The expansive pressure is generated from the excessive increment in the volume of corrosion products, which is four to six times bigger than the steel volume [4]. When the mechanical pressure induced by the corrosion of reinforcement exceeds the tensile strength of concrete (which is a tenth of its compression strength), cracks will be formed and the durability will be reduced dramatically. In this regard, the durability of an RC structure is governed by the severity of reinforcement corrosion [4].

Corrosion can occur without visible indication till it creates cracks on concrete surface. In the context of structure safety, detection of cracks in a structure can be considered a late indication of the structural strength status. Also, repair cost of concrete structure due to corrosion cracks can be extremely high, estimated cost of maintenance and repair of concrete infrastructure due to corrosion around \$100 billion dollars all around the world [5]. Therefore, it is important to employ a monitoring system for the detection of corrosion. This can improve the safety, reduce the cost of repair and lengthen the structural service life. The system should desirably provide the structure's health status to facilitate appropriate remedial that achieves cost-effectiveness.

Several non-destructive tests (NDT) have been developed for in-situ detection of steel reinforcement corrosion in concrete such as surface potential measurement, linear polarization measurement and electrochemical impedance spectroscopy can detect steel reinforcement corrosion satisfactory in a qualitative manner [6]. Nevertheless, majority of these methods provide predictive indications for corrosion, such as the rate or potential of corrosion not the current state of corrosion. In addition, it is necessary to have a method that enables continuous monitoring of steel reinforcement corrosion so that warning of structure deterioration can be provided as early as possible to realize strategic maintenance.

Due to the unique features of fiber Bragg grating (FBG) sensing technique, it was adopted in this study as a monitoring tool for assessing corrosion of steel reinforcement in concrete. FBG sensors possess numerous advantages for practical applications, such as immunity to electromagnetic interference, small size and lightweight, corrosion resistance, ability to be multiplex and capable to receive signal from sources located up to a few kilometers away. Moreover, FBG can monitor pressure [7], temperature [8], strain [8], and force [9] which are some of the main engineering parameters required. Therefore, FBG sensors have attracted the attention of civil engineering communities over the past decade for structural health, vibration and seismic response monitoring [10].

Tilted FBG or laser ablated clad grating fiber sensors can be used for the monitoring of corrosion of steel reinforcement in wet condition based on the surrounding refractive index (SRI) variation of the chemical or electrochemical transformation that take place in corrosion process see [11], [12], and [13]. In this paper a new approach is introduced to monitor corrosion process of steel reinforcement in concrete by bare FBG strain sensor. The monitoring system consists of a bare FBG strain sensor that is physically attached on the surface of steel bar and overlaid with a polystyrene foam layer for protection. The bare FBG strain sensor will detect expansive mechanical pressure from the formation of steel corrosion in the form of expansive rust. To the authors' best knowledge, there is limited literature reports on the direct application of bare FBG sensors to steel bar for corrosion monitoring. For example, see [4] used a FBG strain sensor covered by epoxy resin for protection, with the fiber being arranged in a loop of 75 mm in diameter around a 20-mm steel bar. On the other hand, [14] introduced another method of sensor mounting and procedure for signal detection using metallized FBG, which was coated with Fe-C film where its composition and parameters are FeSO4_7H2O (40 g/L), Citric acid (1.2 g/L), L-ascorbic acid (3.0 g/L), pH (2.5) and I (30 mA/cm2). On the contrary, bare FBG sensors in this study were in direct contact with corrosion environment, to examine the feasibility of detection, monitoring and evaluation of steel reinforcement corrosion in concrete based on strain change. The study also aims to investigate the applicability of FBG sensor mounting technique, its reusability as well as the capability to detect concrete fracture as a result of steel reinforcement corrosion.

## II. Principle of Monitoring Steel Bar Corrosion by FBG Strain Sensor

The FBG strain sensor is a type of optical fiber sensor that prepared by exposing the core of a glass fiber to UV laser using a phase mask technique [15]. This exposure creates a fixed index modulation by an increment of refractive index of the core of glass fiber. Fig. 1 shows the core and the cladding cross section of a glass fiber along with a segment of optical fiber with a periodic variation of refractive index in the core. This periodic modulated fiber segment is called fiber Bragg grating that reflects specific wavelengths of light and allows the others to transmit.

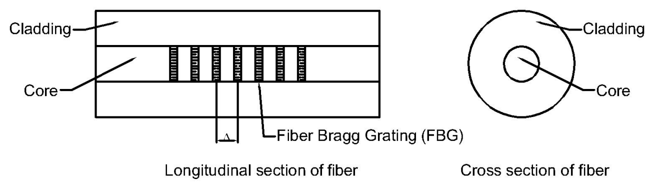



Fig. 1. Cross and longitudinal sections of FBG.

A small quantity of light is reflected from FBG at each variation of periodic refraction. These reflected light signals merge to a single giant reflection at a distinct wavelength. This situation is called Bragg condition, and Bragg wavelength is the wavelength where Bragg condition takes place. This Bragg wavelength ($\lambda_B$) can be changed by changing either effective refractive index ($n_{eff}$) or grating period ($\Lambda$) or both, this changes can be expressed as:

$$\lambda_B = 2\, n_{eff}\, \Lambda \quad (1)$$

The parametric variations in the grating region due to strain or temperature will lead to a shift in the Bragg wavelength. This wavelength shift can be used to measure strain and/or temperature [16].

## III. Experimental Work Details

### *A. Sensor mounting method*

Corrosion detection is major key to determine the health state of a structure, therefore there was many studies to detect the corrosion level and its effect on the structure. Because of the outstanding advantages of FBG sensors over other sensors, FBG sensors have been employed for the detection and monitoring of reinforcement corrosion. In general, the FBG sensors have the same principle of acquiring data, however different mounting technique and data analysis were studied. According to [4] had used tight- buffered FBG fibers and covered by epoxy resin to protect the fiber and to reduce the effect of the fiber on the concrete specimen integrity. Also, he used bare FBG senor properties which are the flexibility and precision to detect corrosion-induced crack where the fiber was placed as a hoop around impeded reinforcement. However, see [14] had stripped at the grading part of the fiber with two layers, first layer is Silver film followed with Fe-C sensing film. The purpose of choosing Fe-C sensing film is its ability to change longitudinally due to rusting reaction. The film changes can cause strain on FBG fiber which will lead to wavelength shift. [17] in other hand used different approach of mounting and sensing technique to sense corrosion level. A standard FBG strain fiber fixed between twin steel rebars perpendicularly to rebars axis. The principle is to use the expansion of the twin rebars' diameters due to the corrosion product formation and that will cause the twin bars to push each other. The FBG fiber was fixed at each rebar therefore it can detect the longitudinal strain cause from the movement of rebars' centers from each other. In

[18] has used FBG sensor to detect the concrete changes around the reinforcement, his technique is similar to [4] where a loop was created around the reinforcement with an offset to detect the concrete's changes. His study found a relationship between the axil strain due to the rebar corrosion and the wavelength shift of FBG sensor.

Due to fragile structure of bare FBG, it is hard to embed bare FBGs in concrete structures without any protection, therefore it is necessary to develop encapsulation techniques for bare FBG strain sensors [19]. Moreover, most of the studies give general indication of the corrosion level and other studies' cost of sensor manufacturing is very high. In this paper, a new sensor mounting is designed to achieve more accurate indication of reinforcement corrosion and minimize the cost of sensor manufacture and mounting. It is noteworthy that embedded FBG fibers are foreign entities to host structures, mechanical mismatches may eventually lead to alteration on sensors' responsive behaviors, thus the measurement interpretation becomes complicated. Also, FBG strain gages have to bear extra stress caused by structural perturbation [20]. In order to overcome this shortcoming, a bare FBG sensor was directly mounted on the physical surface of steel reinforcement. This mounting method was intended for protecting the FBG sensor from being damaged by stresses that incur during concrete hardening and the service exposure that follows, such as shrinkage, expansion and creep. Furthermore, no encapsulation was applied on the FBG sensor because encapsulation may alter and possibly reduce the sensitivity of the sensor [19]. The proposed mounting method should accommodate free formation of expansive rust on steel, without sacrificing the sensitivity of corrosion detection and evaluation. Polystyrene foam was used as a buffer material that would provide protection and sufficient room for the FBG strain sensor to detect strain change in accordance to any stress that takes place as a result of corrosion activities. Notably, the inner cavity made by polystyrene foam and the bend sensitivity [21] of the FBG are the two enabling factors of the FBG sensor to corrosion detection. In the installation of the sensor, the FBG was laid over a flatly grinded surface of the reinforcement. This is to eliminate the possibility of erroneous reading due to the uneven strain on the FBG during the corrosion process. When the corrosion takes place at the grinded area under the FBG sensor, the corrosion products will grow [4] and subsequently bend the FBG sensor. As the corrosion continued, the accumulated corrosion product (corrosion-induced expansion [4]) continued to increase and apply greater strain on the FBG sensor. The applied strain on the FBG can be detected in the form of wavelength shift in the output spectrum. With reference to the arrangement layout shown in Fig. 2, the polystyrene foam was first cut to give a triangular shaped void and later used to "cover" the steel reinforcement part pre-mounted with FBG strain sensor. Epoxy resin (Araldite repair steel) was used to bond the polystyrene foam with steel reinforcement in such an arrangement that the perimeter of the contact area was totally sealed, leaving a gap inside in between the sensor and polystyrene foam. Furthermore, the FBG sensor was fix on the steel reinforcement by using epoxy, also holes are created at the sides of the polystyrene foam cover in a such way that allows the water to go through without the cement paste, where the cement paste has higher viscosity compare to water then the cement get hardened and water can travel though concrete porosity and through polystyrene foam to reach the reinforcement bar. Polystyrene foam was chosen for this study because of its good energy absorption and deformability that are deemed to offer good protection to FBG strain sensor from damaging actions such as concrete pouring, compaction, hydration and other types of stresses under service exposure. Furthermore, polystyrene foam is lightweight, low-cost and can be easily shaped to suit different arrangements.

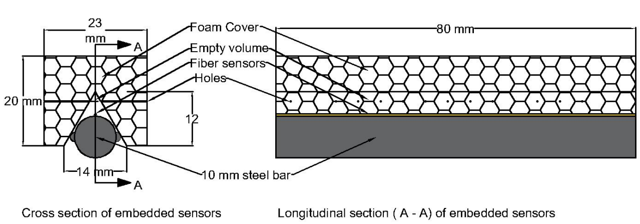
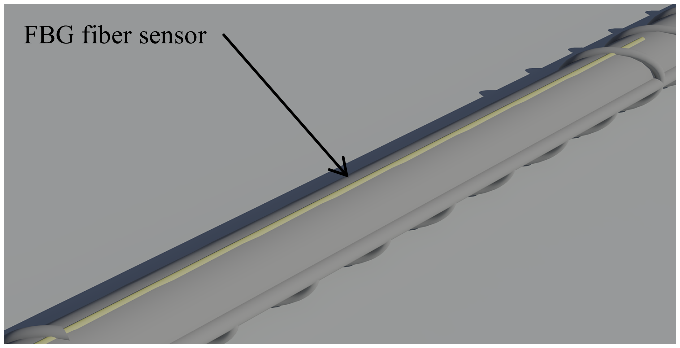



Fig. 2. Layout of polystyrene foam cover for FBG strain sensor.

Due to the delicate and fragile nature of glass fiber, the mounting surface was carefully grinded and smoothened before the FBG fiber sensor was bonded by epoxy resin. The epoxy resin is allowed 6 hours of curing, before the polystyrene foam was placed to cover the sensor. Fig. 3 shows the procedure for preparation and sensor mounting. As for the extension optical fiber which connects the FBG strain sensor with the interrogator (National Instrument PXIe-4844) was housed inside a plastic tube for protection from being exposed to concrete as shown in Fig. 4.

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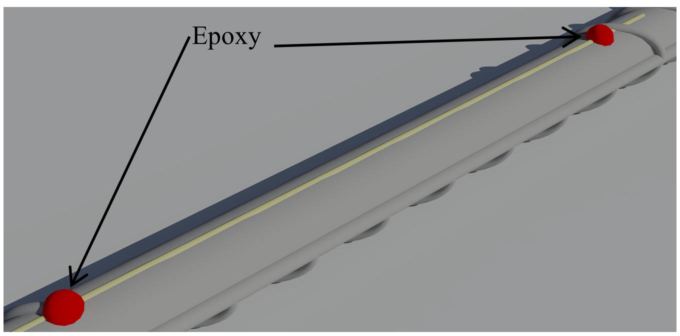


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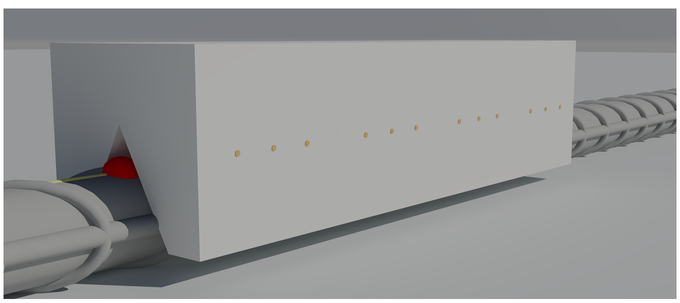

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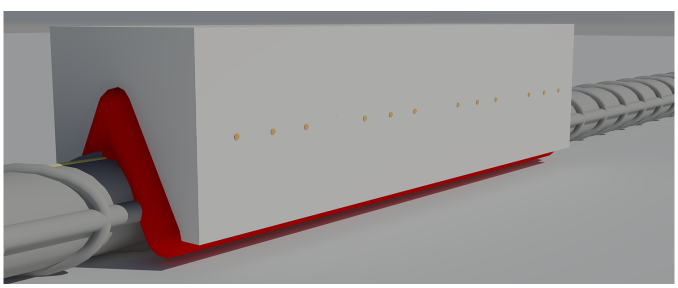


*(d)*

Fig. 3. Procedure for mounting FBG strain sensor on steel reinforcement bar. (a) Place fiber sensors on the grinded surface of steel reinforcement. (b) Bond the two ends of FBG strain sensor to steel reinforcement with epoxy resin. (c) Place polystyrene foam to cover FBG strain sensor. (d) Apply epoxy resin to seal the perimeter of polystyrene foam with steel reinforcement.

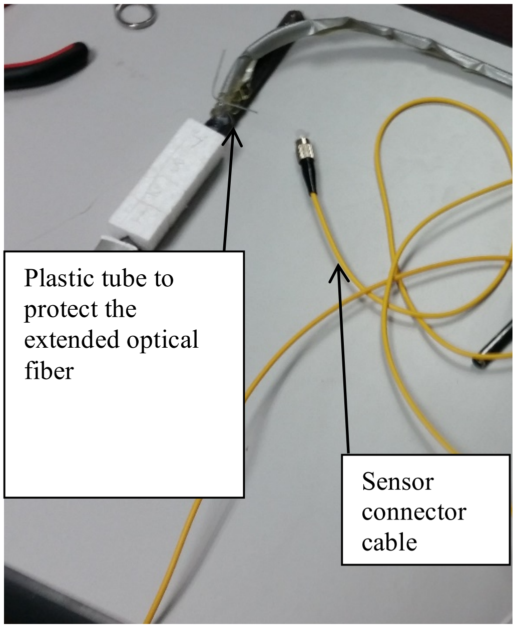



Fig. 4. Photo of FBG strain sensor mounted on steel bar with polystyrene foam cover.

*B. Concrete specimen preparation*

Two 200 x 100 mm concrete cylindrical specimens were prepared for the study, as shown in Fig. 5. Ordinary Portland cement was used as the binder. The concrete mix was designed by referring to a previous work [22] with binder to water ratio of 0.55. The proportional ratio for binder, coarse aggregate and fine aggregate was 1:1.65:3, with maximum coarse aggregate size of 10 mm. A structural grade deformed steel bar of 10 mm in diameter was placed at the center of specimen. After casting, the specimens were demolded after 24 hours and cured inside a water tank for 16 days. Among the two specimens, one was used to assess capability of the FBG strain sensor in detection and evaluation of steel corrosion, while the other one was intended for investigating the feasibility of FBG strain sensor in assessing concrete cracking. The top and bottom faces of the second specimen were coated with epoxy resin to prevent concrete from directly in contact with NaCl solution during accelerated corrosion process, considered as an attempt to mimic the actual exposure condition of a typical RC element to corrosion, in which moisture and chloride ions are penetrating from concrete cover and in a direction perpendicular to steel reinforcement.

Fig. 5. Specimen after curing.

### *C. Experimental measurement and corrosion acceleration*

The experimental measurement setup is shown in Fig. 6. In each of the two experiments, one specimen was placed vertically into a plastic container filled with 5% NaCl solution by mass. The water level was adjusted to have a height of 20 cm from the specimen base. A portable DC Power Supply (MEGURO MP 303-3) was used to perform accelerated corrosion by impressed current technique [23]. The FBG strain sensor that was embedded in the concrete specimen was connected to an optical sensor interrogator (National Instrument PXIe-4844). Monitoring and data acquisition were controlled using LabVIEW software (National Instrument). The measurement was configured to have data recorded at one-hour intervals. Two specimens have been prepared for this investigation. The accelerated corrosion process was conducted for 36 and 144 hours for the first and second specimens, respectively.

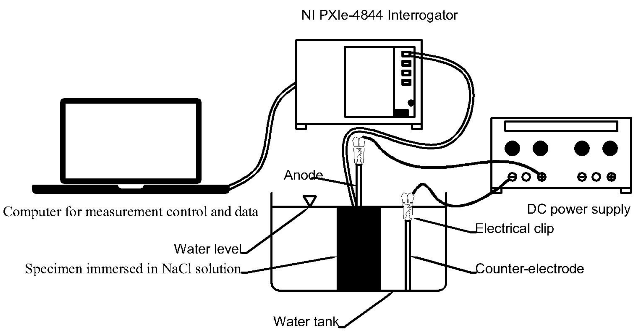



Fig. 6. Experimental measurement setup.

To accelerate corrosion process of reinforcement, an impressed current technique was used. To perform the technique a DC power supply was needed, where the positive terminal was connected to the embedded steel bar to form the anode. To form an electrical circuit, the other terminal (negative) was connected to a bare steel bar immersed in the same water tank as the specimen. The other steel bar became the counter-electrode [23]. The solution was electrically conductive due to the 5% of sodium chloride. Therefore, the oxidation of steel bar can be increased by removing electrons from the anode bar to form $Fe(OH)_2$ and $Fe(OH)_3$ [24].

## IV. Results And Discussion

Following the end of accelerated corrosion process for the first specimen, FBG measurement was stopped and the specimen was break opened to examine the conditions of steel bar and the FBG strain sensor. Fig. 12 shows the condition of steel bar found in the first and second specimen at the end of accelerated corrosion process. As given by the time history plot in Fig. 7 suggested the occurrence of accumulated corrosion activities that have introduced stresses cause gradual change in the FBG wavelength over time. Also Fig. 7 relates the change of FBG wavelength with the level of corrosion, expressed in terms of mass loss of steel by percentage, in other words it is the weight loss of steel bar (Faraday's law) by the original weight of the bar before start of corrosion process. Fig. 8 shows the development of FBG wavelength measurement for the second specimen against time and steel corrosion percentage.

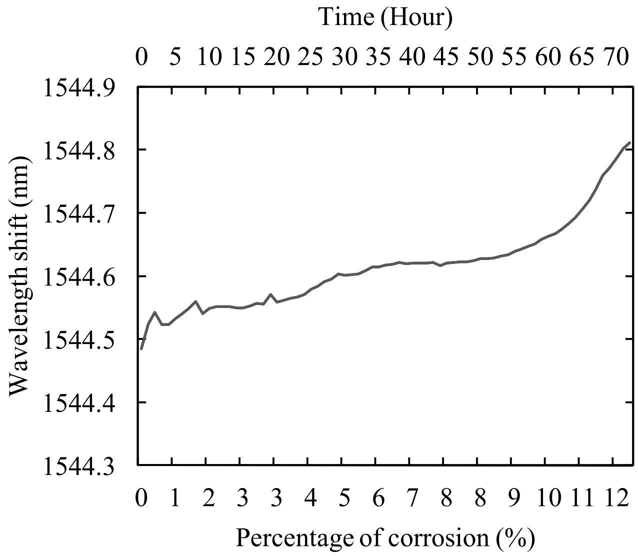



Fig. 7. Wavelength shift of specimen 1 versus time versus percentage of corrosion.

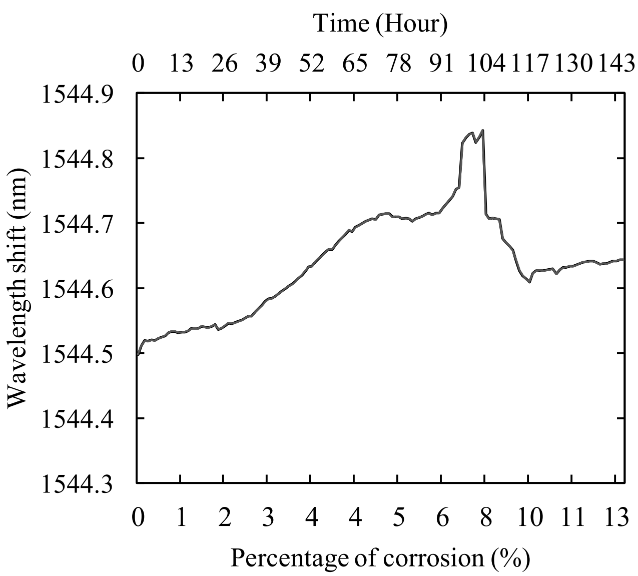



Fig. 8. Wavelength shift of specimen 2 versus time versus percentage of corrosion.

The rate of steel mass loss by corrosion was calculated by the following equation based on the Faraday's law [22]:

$$\frac{dM_s}{dt} = 2.315 \times 10^{-4} \times I_{corr} \quad \left(\frac{g}{s}\right) \qquad (2)$$

Where, $M_s$ is mass of steel loss consumed in gram, t is time in second and $I_{corr}$ is the amount of current flowing through the electrochemical corrosion cell in ampere. The electrochemical corrosion cell is made of the anode bar inside the specimen and the counter-electrode bar inside the water tank. The steel corrosion by percentage of mass loss can be computed by the following:

$$M_{\%} = \frac{M_s}{M_O} x100 \qquad (3)$$

Where, $M_{\%}$ = The steel corrosion by percentage of mass loss (%) and $M_O$ = Original weight of steel bar (g). Throughout the corrosion process, the current voltage was found to fluctuate with the highest variation of 30 volts, which was minor and therefore it can be considered that the current voltage was almost constant and stable throughout the experiments. Table I shows the current value for the two specimens.

TABLE I

CURRENT VALUES FOR EACH SPECIMEN

| Duration | Specimen | Ampere value |
|---|---|---|
| 0 to 72 | 1 | 0.25 |
| 0 to 96 | 2 | 0.1 |
| 96 to 120 | 2 | 0.25 |
| 120 to 144 | 2 | 0.15 |

TABLE II

WAVELENGTH VALUES FOR SPECIMEN 2

| FBG Wavelength (End of the fourth day) (nm) | FBG Wavelength (Beginning of fifth day) (nm) | Corrosion time (Hour) | Corrosion percent (mass lost over original mass) (%) | Corrosion (Increment) (%) |
|---|---|---|---|---|
| 1544.72 | | 91 | 6.156 | 0.068 |
| 1544.72 | | 92 | 6.223 | 0.068 |
| 1544.73 | | 93 | 6.291 | 0.068 |
| 1544.74 | | 94 | 6.359 | 0.068 |
| 1544.75 | | 95 | 6.426 | 0.068 |
| 1544.76 | | 96 | 6.494 | 0.068 |
| 67-hour break | | | | |
| | 1544.82 | 97 | 6.562 | 0.068 |
| | 1544.83 | 98 | 6.629 | 0.068 |
| | 1544.83 | 99 | 6.697 | 0.068 |
| | 1544.83 | 100 | 6.866 | 0.169 |
| | 1544.82 | 101 | 7.035 | 0.169 |
| | 1544.83 | 102 | 7.204 | 0.169 |
| | 1544.84 | 103 | 7.373 | 0.169 |
| | 1544.71 | 104 | 7.543 | 0.169 |
| | 1544.70 | 105 | 7.712 | 0.169 |
| | 1544.70 | 106 | 7.881 | 0.169 |
| | 1544.70 | 107 | 8.050 | 0.169 |

The procedure adopted in this study for mounting FBG strain sensor was considered successful in ensuring robustness and sensitivity of FBG strain sensor to detect steel corrosion and concrete cracking during extended period of accelerated corrosion. Also, the strain FBG has the ability to detect the start of crack formation. The crack has been created from the bottom of the specimen. However, no evidence of significant concrete cracking could be spotted by visual inspection at proximity of the FBG strain sensor. It was considered that the polystyrene foam cover has help reduced, if not eliminate cracking to take place by absorbing the stresses generated from the formation of expansive rust. FBG strain sensor's wavelength shows increment correlated with the increment of the corrosion level. After 96 hours of corrosion process, we took a break for 67 hours before the impressed current procedure resumed. During the break, the progress in wavelength shift has drastically slowed down and the difference between the recorded wavelength at the start (1544.762nm) and that at the end (1544.748nm) of break was only 0.014 nm, way smaller than any of the recorded wavelength shift in an hour when impressed current procedure was conducted. This is an important evidence connecting the wavelength response of the FBG sensor to the corrosion process. The temperature of the laboratory was carefully kept constant throughout the testing period. Thereby, the influence of temperature change on wavelength shift could be disregarded. The measured wavelength shift was solely caused by the progression of steel corrosion. The accuracy and sensitivity of the measurements are dependent upon the optical interrogator system [25] and the FBG strain sensor. The interrogator wavelength accuracy is 1 pm and the FBG strain sensitivity is $\Delta\lambda = 1.2$ pm/$\mu\varepsilon$.

Fig. 12a shows that the responses attained from the sensors are due to the volume of the corrosion products layer. However, the FBG wavelength reading was found to be almost constant for Specimen 2 during a period of 97 hours to 103 hours after corrosion has started.  constant values This inferred that in this period, the continuing corrosion activity did not induce significant stress to the FBG strain sensor. In other words, the corrosion products at this stage act as fluid which passes around the fiber without changing the wavelength shift. After that stage, which is at the beginning of the fifth day, cracks were observed to have propagated from the bottom of the specimen at 7.54 % of corrosion. Nevertheless, the first specimen has reached over 12% of corrosion level without any indication of crack, and the reason behind that is the non-uniformity of the reinforcement corrosion. Table I shows the current's Ampere and voltage, where the ampere has changed for the second specimen to keep the voltage constant for safety reasons. Due to the low Ampere at the beginning of the second specimen the reinforcement corrosion was more uniform. However, the first specimen started with high ampere value which lead to less corrosion uniformity. Fig. 12 shows the actual corrosion at the location of the sensors. In other words, the reinforcement part that had most corroded was not on the sensor area. After 103 hours into the corrosion process for specimen 2, there was a decline in the wavelength shift which signified the change in corrosion products arrangement. As the polystyrene foam was in contact with concrete, cracks that formed in concrete have created a release stress on the polystyrene foam. Therefore, the polystyrene foam inner volume was increased to allow for the corrosion products to fill the side boundaries of the polystyrene foam. A marked jump in the wavelength shift as noted between 96 hours to 97 hours after the corrosion process initiated. The jump was corresponded to the increase in electric current, where the increment occurs to allow the current voltage to be constant throughout the experiment, the fifth column in Table II shows the corrosion increment which is the corrosion percent of the current hour minus the corrosion percent of the previous hour (6.291 - 6.223 = 0.068 %).

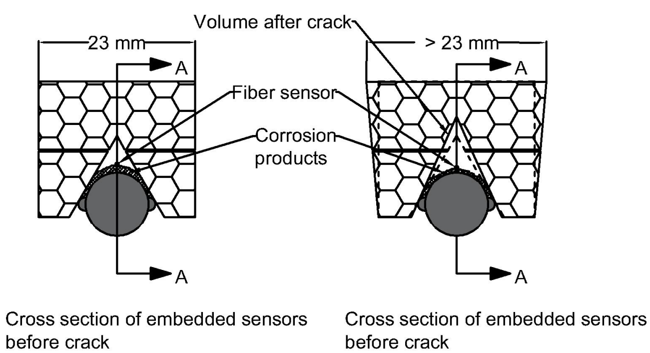



Fig. 9.  Sensor cross section before and after crack.

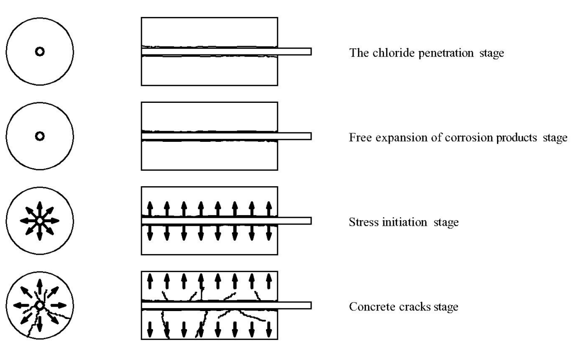
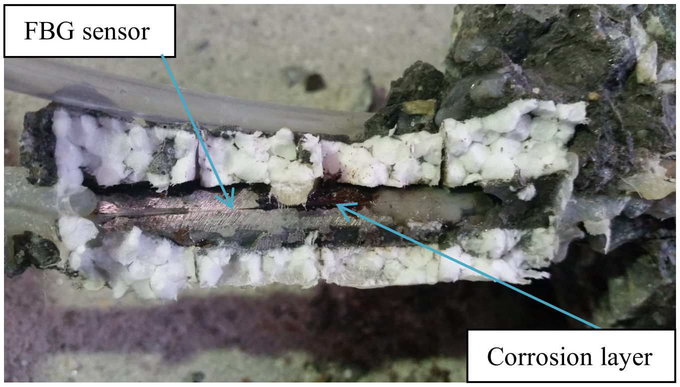



Fig. 10.  Reinforcement corrosion stages.

The FBG strain sensor has proven its capability to detect the three stages of corrosion process out of four stages of corrosion process [22]. The first stage is associated with chloride penetration and corrosion initiation. First stage takes years in actual corrosion process and in the current study, it can be considered as the initial two hours after corrosion has started. The second stage was defined as the time during which free expansion of corrosion products, namely rust occurred, which was during the 101 hours of the corrosion process. In this stage, the voids surrounding the steel bar were occupied by rust. The third stage is regarded as the stress initiation where the rust has induced stresses on the concrete, resulting in cracking events. In this study, the third stage of steel corrosion could not be clearly identified by the FBG strain sensing because of the isolation of the sensors from concrete material by the polystyrene foam cover, the last stage was evident, with which the FBG wavelength shift has registered a drop after 103 hours of corrosion, a result of intensified cracking that gave change to concrete stress transfer over the polystyrene foam cover. After the release of the stresses on the polystyrene foam cover the inner volume of the polystyrene foam cover has been increased to allow the corrosion products to flow and reduce the cumulative corrosion products under the sensor fig. 9. The stages are illustrated in Fig. 10. Fig. 11 shows the cracks on the second specimen.

Fig. 11. Rust stain emerged from concrete cracks.

At the end of experiment, both specimens were crack opened to examine the conditions of FBG strain sensors. Fig. 12 shows the conditions of FBG sensors in specimen 1 and 2 after corrosion process. It is obvious that specimen 2 has developed a more severe corrosion than Specimen 1, which is confirmed by our theoretical calculations. Fig. 12a shows the corrosion layer formed on the steel bar that induced stress on the FBG sensor, this layer was formed from two types of corrosion products namely, adherent and non-adherent products in which the adherent layer is deposited over the bar surface. On the other hand, the non-adherent layer was loosely bounded to the metal surface and it may dissolve into the solution during the corrosion process [26]. Therefore, at high corrosion level the non-adherent corrosion products with the presence of solution may act as fluid as shown in Fig. 12b. Upon detailed examination, the FBG sensors in both specimens were found intact and their bonds with steel reinforcement remained sound. In other words, the sensors were found to be in good working condition and could be recycled for other use by detaching them through from the steel bars through heating of the bonding epoxy resin. This finding is important in validating the feasibility of the mounting procedure for FBG strain sensor developed for monitoring and evaluating steel reinforcement corrosion in concrete.




*(a)*

*(b)*

Fig. 12. Condition of FBG strain sensors in specimen 1 and 2 after corrosion test. (a) specimen 1. (b) specimen 2.

## V. Conclusions

Detection and evaluation of steel reinforcement corrosion in concrete structures are essential for early identification of causes that lead to structural failure. Accurate assessment for steel reinforcement corrosion helps reducing the cost of remedial work. This study examines the practicality of using FBG strain sensing technique in monitoring steel reinforcement corrosion activity and the resulting concrete cracking. The FBG strain sensors have demonstrated good sensitivity in the form of wavelength shift against the progression of steel bar corrosion in concrete. However, it is worth noting that FBG sensor is a point based sensor and the area of detection is limited to vicinity of the sensor. Distributed FBG sensors may be able to provide a more precise measurement by means of greater coverage for larger structures. The FBG strain sensors have also provided indicative change in wavelength shift due to propagation of concrete cracks. The inclusion of polystyrene foam has provided good protection to the sensor fiber during concrete casting and hardening. In addition, the whole mounting procedure was robust in securing the integrity of FBG strain sensors throughout the corrosion process, which involve generation of stresses by rust expansion and cracking of concrete where the polystyrene foam protected the fiber during the concrete pouring and concrete hardening process, also at the time of concrete hacking the polystyrene foam absorbs the stresses without harming it.

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